INRA
SCIENCE & IMPACT

May phylloclimate help phenotyping?

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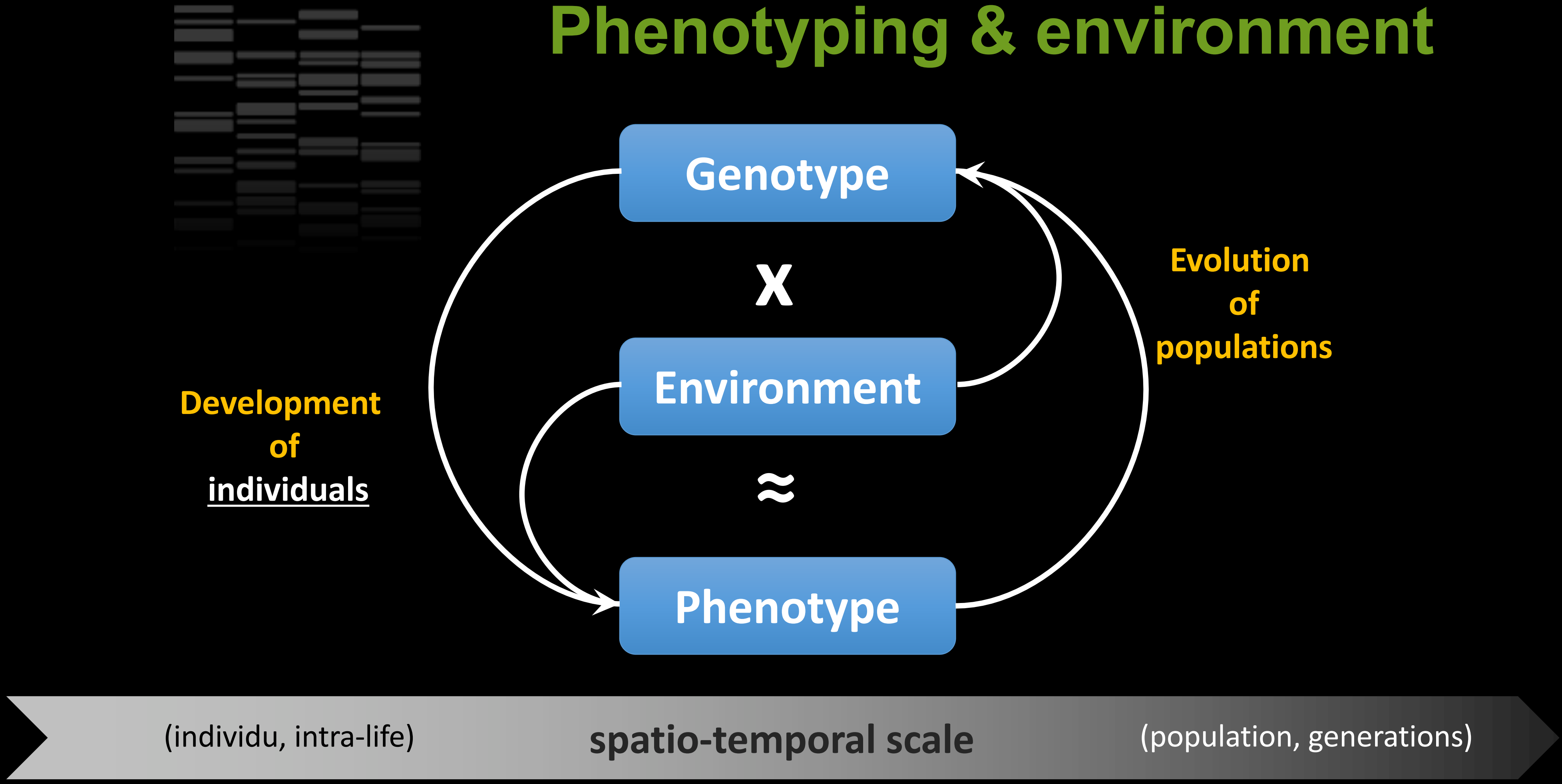
Michaël Chelle

Phenotyping & environment



From the neo-Darwinian model

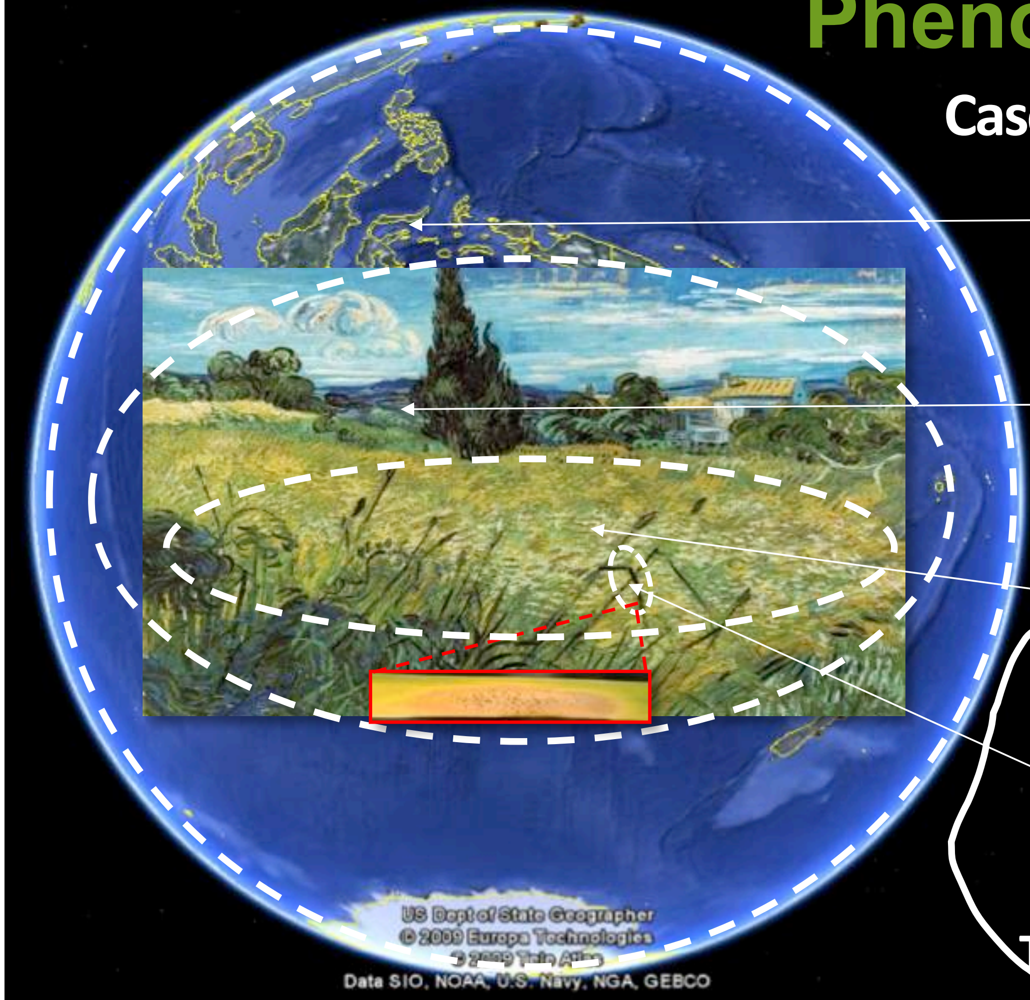
Phenotyping & environment

=> 2 questions / environment

- Which variables do characterize it?
- At which spatio-temporal scale(s) should they be characterized?

Phenotyping & environment

Cascade of environmental scales



Global climate : model/satelite

Downscaling

Mesoclimate : weather station

Filtering by canopy structure

Microclimate : in-canopy

Individualization

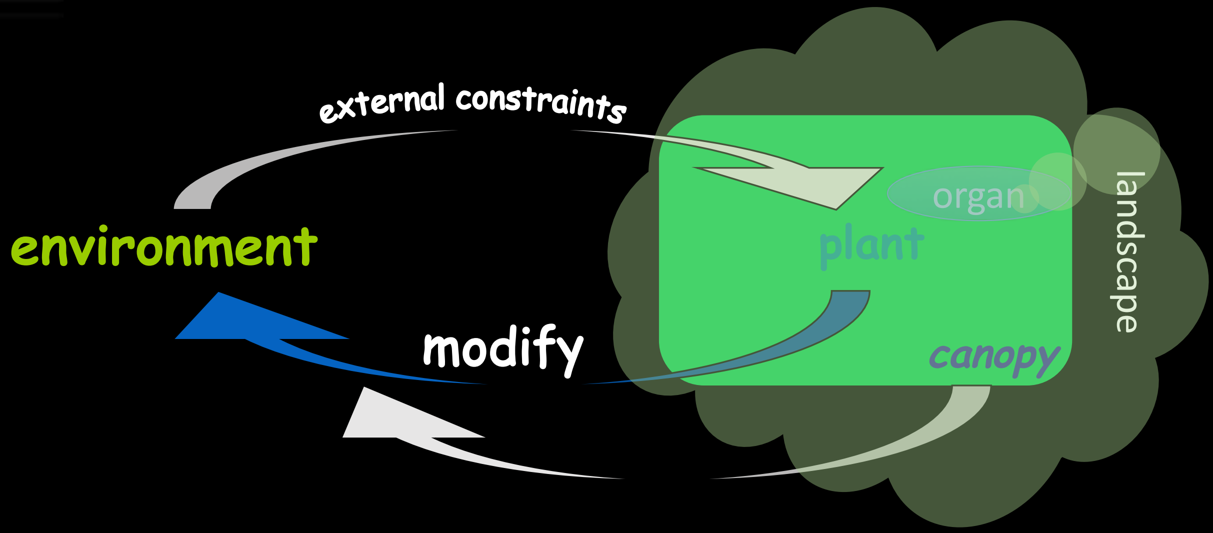
Phylloclimate : organ (leaf)

The scale where biol processes occur!

Phenotyping & environment

What about plant-environment interaction?

environment = resources + information vector



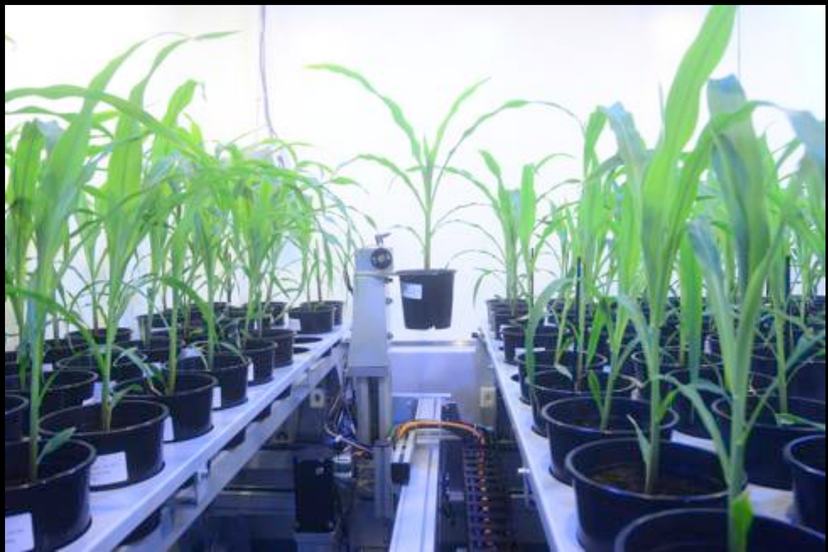
Landscape, canopy, plant, organ, … : which relevant scale for environment?

Phenotyping & environment

Which environment? canopy *vs* plant *vs* organ

from canopy phenotyping (plot ~ mean plant)

towards individual plant phenotyping



Ruckelshausen, A., et al. 2009. "BoniRob–an autonomous field robot platform for **individual** plant phenotyping." *Precision agriculture*

Phenotyping & environment

the canopy?

↓

various systems !

« not the field, but a field ! »
Dr Trevor Garnett

Phenotyping & environment

Which scale for plant-environment studies?

Exchanges within a canopy

From the plant point of view

Topology

Canopy

-> plant

-> interacting organs

From the environment point of view

Spatial proximity

Canopy

-> voxel

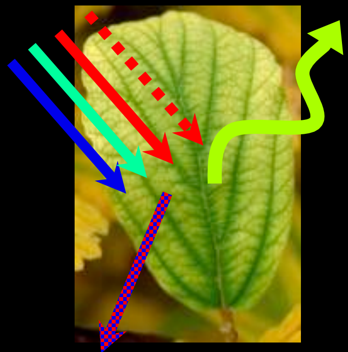
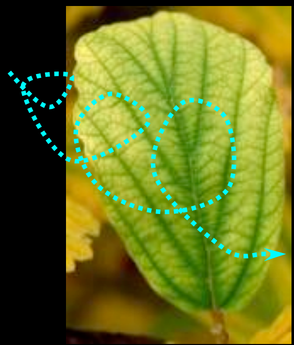
-> close organs

=> Focus on organ scale

Phenotyping & environment

Microclimate perceived by individual plant organs : phylloclimate (Chelle, 2005)

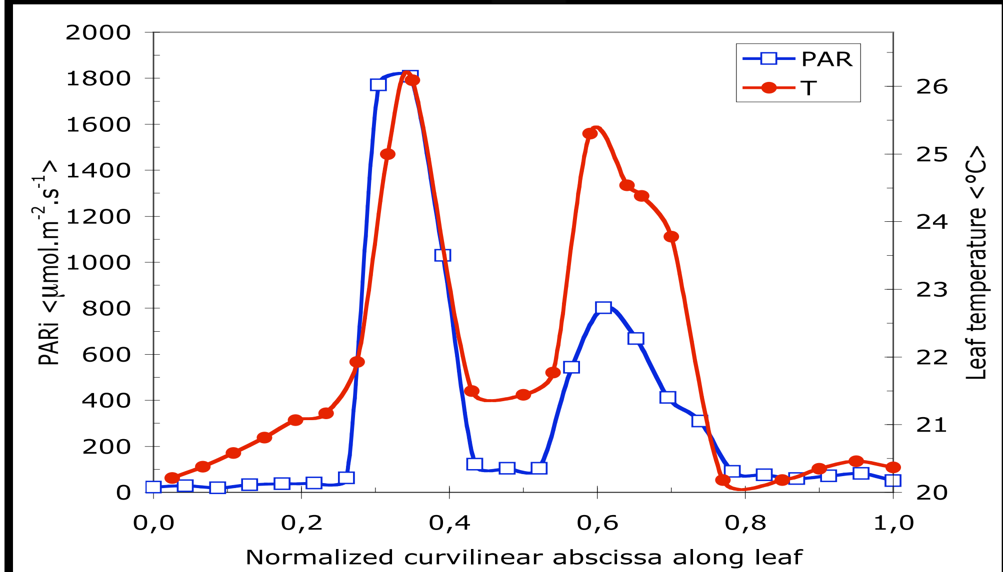
Interface physics - biology

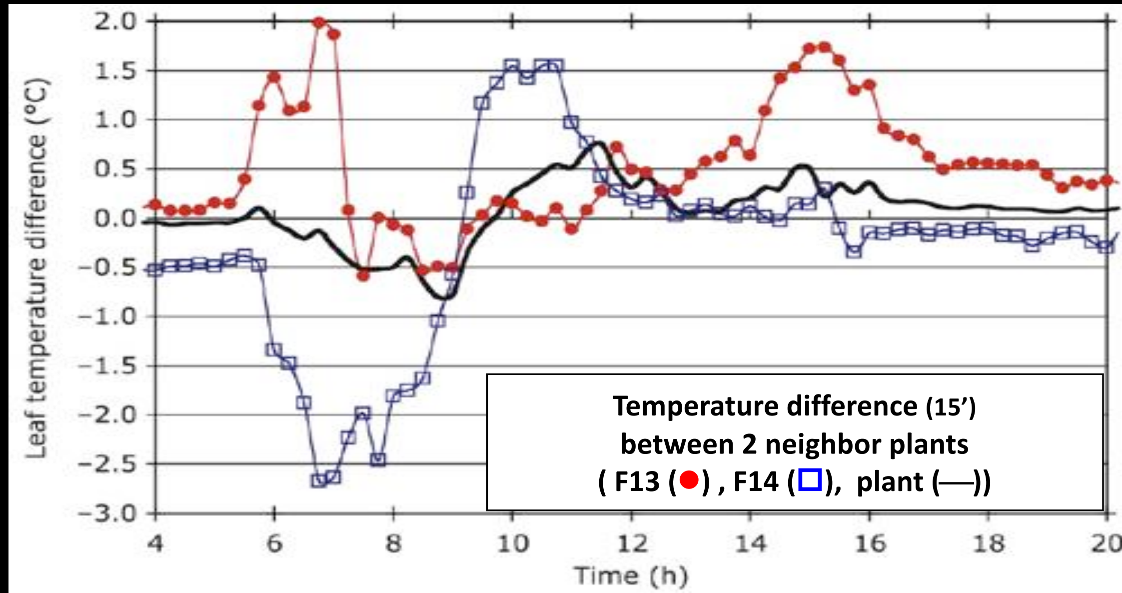
Spectral irradiance	*Surrounding air*	*Organ temperature*	*On-leaf water*
			
UV, PAR, NIR, TIR *blue, red*	*wind speed* *temperature* *humidity* *[CO_2]*	*surface temperature* *within temperature*	*quantity* *wetness duration*
photosynthesis *photomorphogenesis* *pathogens* *energy budget*	*air-leaf exchanges* *thigmomorphogenesis* *energy budget*	*growth & development* *photosynthesis* *quality* *pathogens*	*fungal pathogens* *energy budget*

(Chelle, 2005)

Phylloclimate

Space & time variability





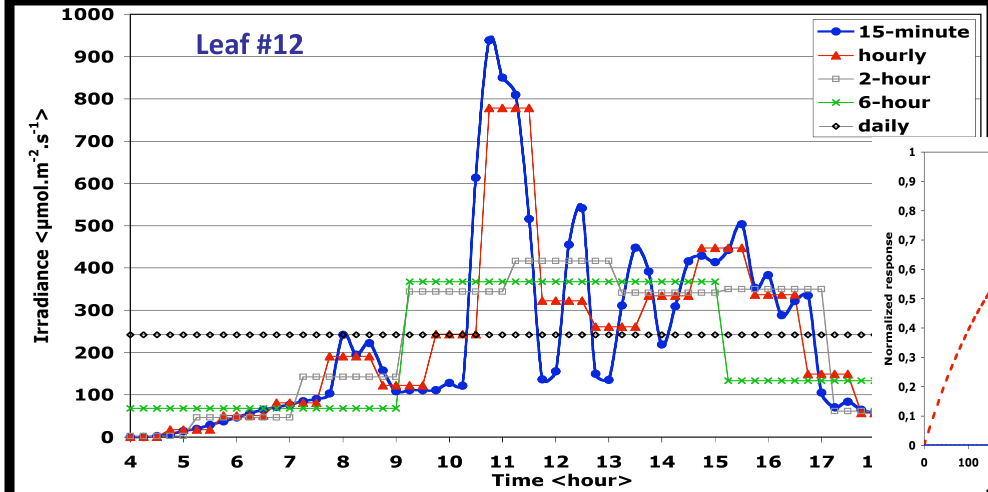
Importance of light variability (sunflecks, penumbra)

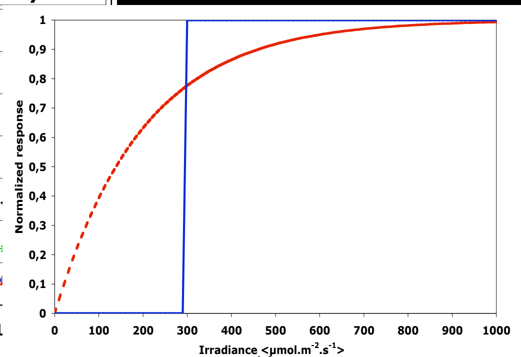
Phylloclimate

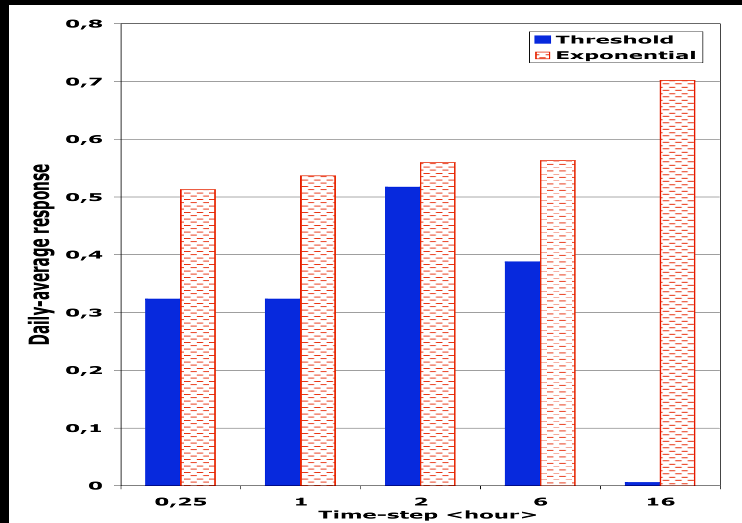
High variability at short time steps (sunflecks)

=> At which scale studying biological processes?

* *Non-linear responses*





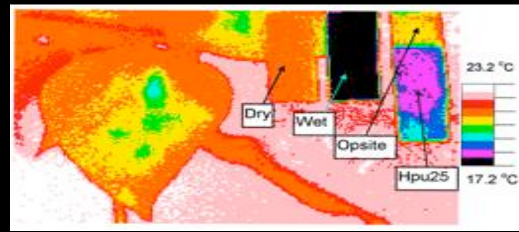


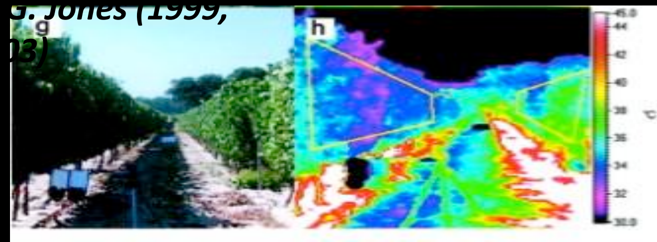
* *Risks : extreme > mean*

Importance of occurrence / average of a process

Phylloclimate

Measurement of 3D spatial distribution





*** Small sensors:** experimentally difficult (plot), plant perturbation*

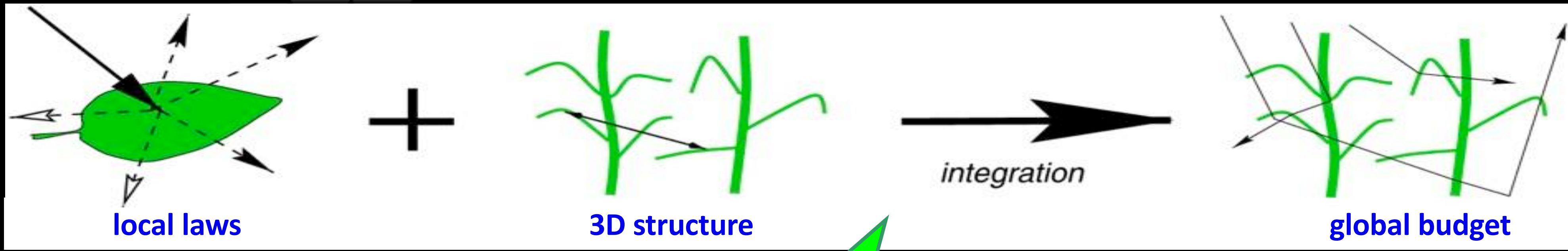
*** Distant sensors:** indirect measurement, hidden parts, 2D-3D matching*

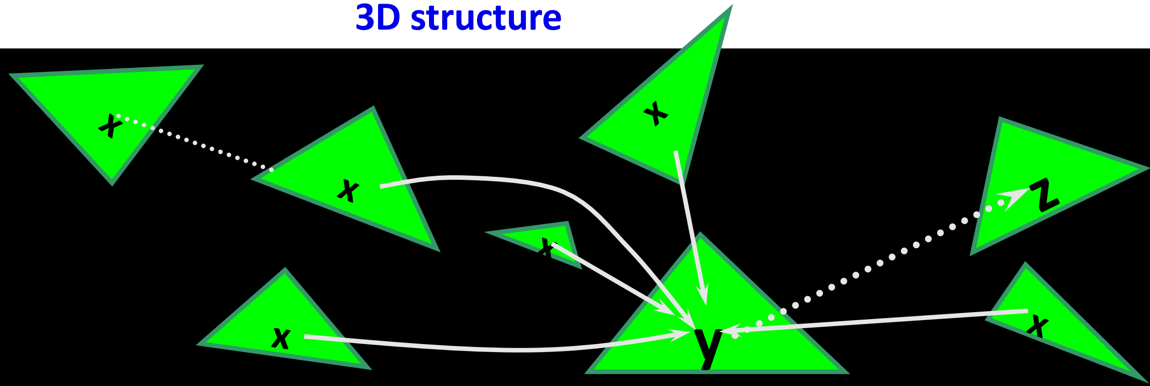
⇒ an alternative: the way of modeling

3D plants structure + top-canopy climate => phylloclimate

Phylloclimate

Modeling of 3D spatial distribution





$$\forall y,z \in S, \quad q(y,z) = q^0(y,z) + \int \cdots \int_{x \in S} R(x,y,z) \cdot T(x,y) \cdot q(x,y) \mathrm{d}x \cdots$$

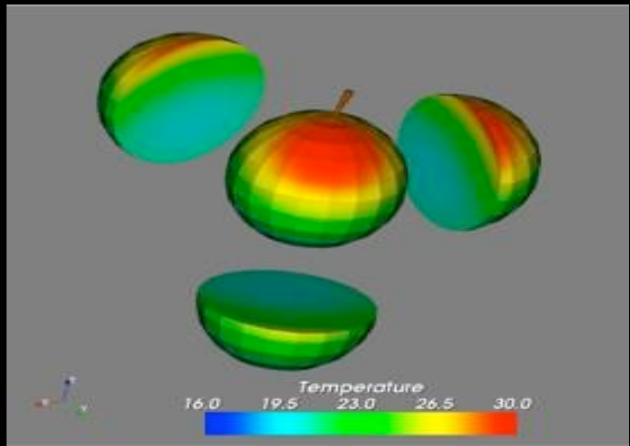
=> solving: Monte-Carlo, discretization, nested, etc

Phylloclimate

Modeling state of art

* Radiation (PAR, R:FR, etc) : *operational models*
* Temperature : leaf, fruit : *2nd step: modeling in progress*
* Water: *(less studied)*
  splash dispersal: *in progress*
  leaf wetness: *starting*

(Chelle et al, 2007)

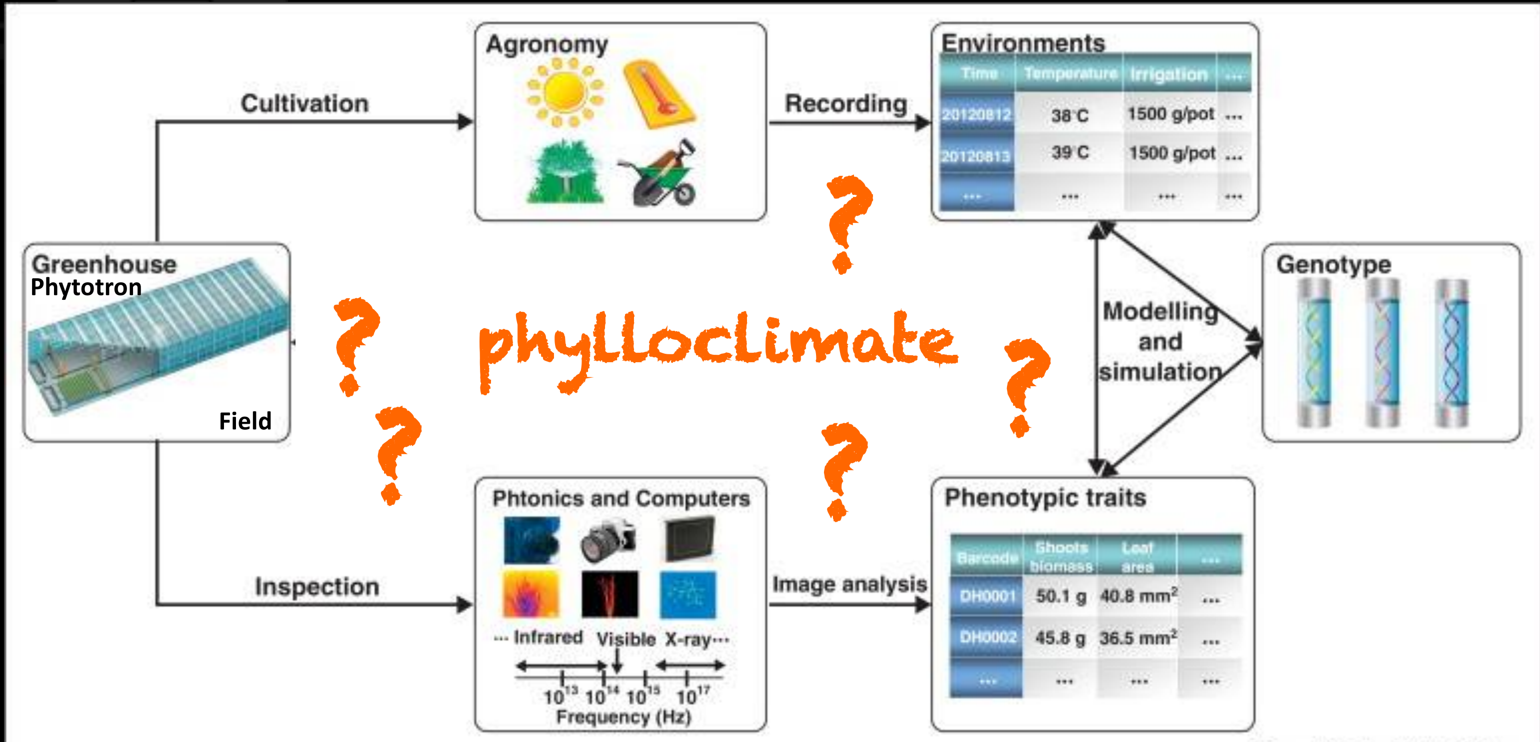


(Fruit: Saudreau et al, 2007;
Leaf: Chelle & Gutschick, 2010)

(Saint-Jean et al, 2004)

Phenotyping & phylloclimate

Why phylloclimate may be important when phenotyping?



From Yang et al., 2013.

Phenotyping & phylloclimate

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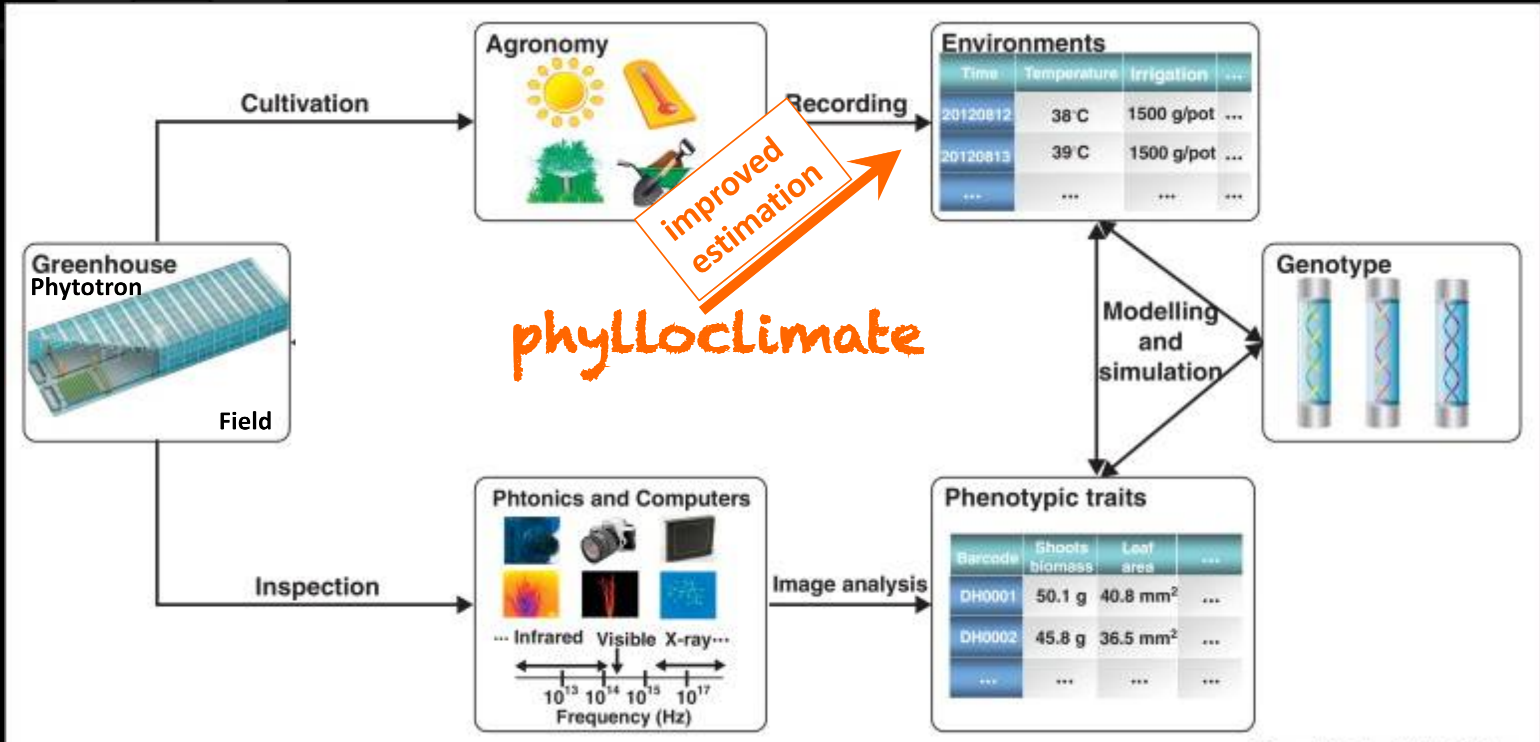

From Yang et al., 2013. Current Opinion in Plant Biology

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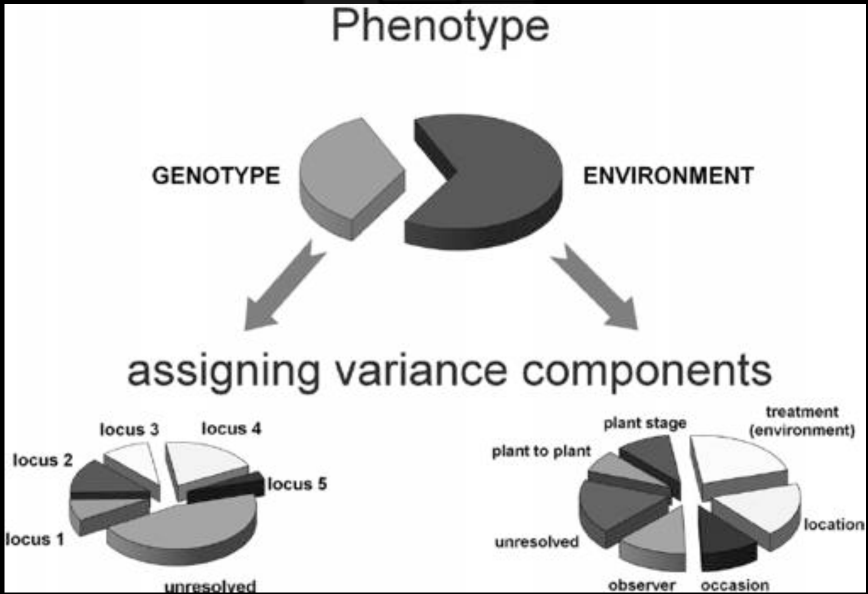
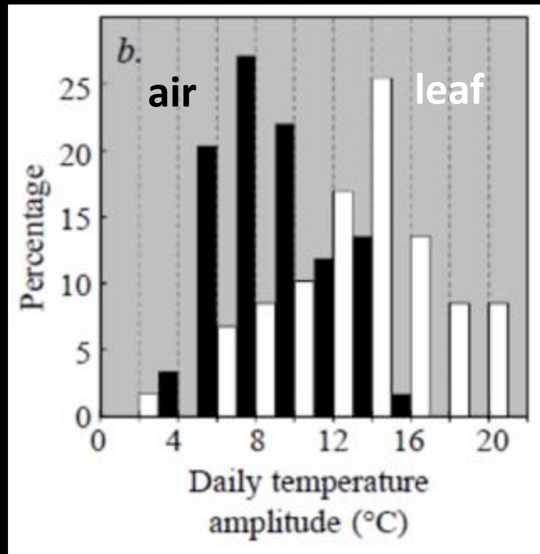


King GJ, Amoah S, Kurup S (2010) Exploring and Exploiting Epigenetic Variation in Crop Plants. Genome 53:856-868.

What happens if the environment is wrongly estimated?



Wheat,, Grignon, june 2012

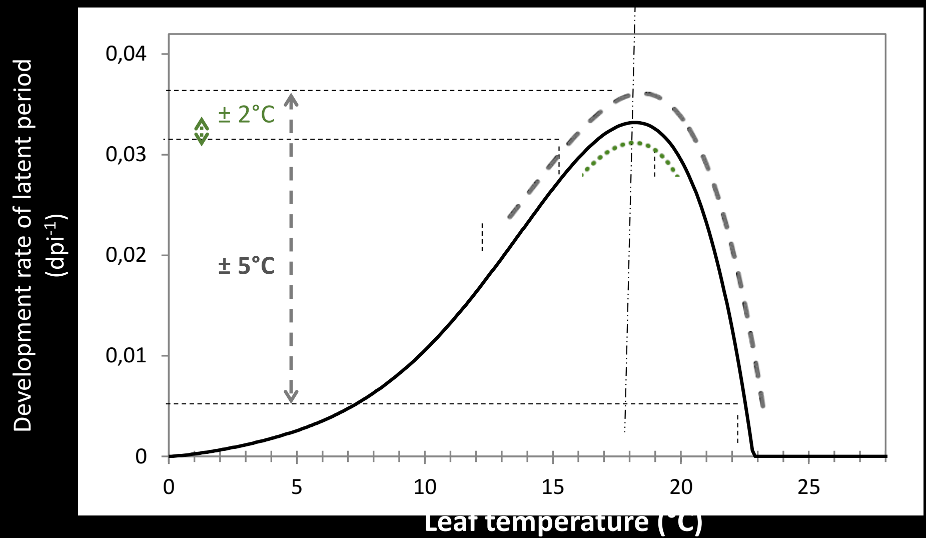
Why phylloclimate may be important when phenotyping?

What if the environment is misestimated?

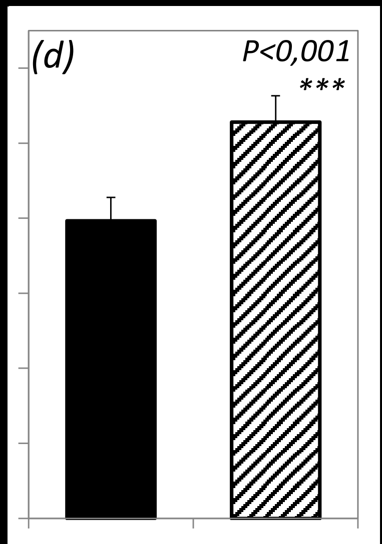
G = P / Ê
but if Ê ≠ E ?

An example with fluctuating leaf temperature

Mean leaf temperature = 18°C



Latent period Z. triticii



- **Knowing same E (T = 18°C),**
  => ≠ P => ≠ G !
- **Knowing ≠ E,**
  => ≠ P => G?

<!> from controlled env. to field phenotyping

Why phylloclimate may be important when phenotyping?

Where do we phenotype plants?

In growth chamber

In greenhouse

In field

But mainly , for the 3 systems, we characterize mesoclimate (sometimes micro-climate)

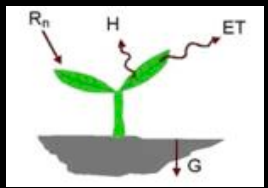
eg air temperature, incident radiation above plants

Why phylloclimate may be important when phenotyping?

BUT, the differences between meso- and phyllo-climate depend on the growing environment !

Radiation

Wind



$T_{leaf1} \neq T_{leaf2} \neq T_{leaf3}$

Leaf energy budget varies between experimental conditions → for a same Tair (meso), Tleaf differs (phyllo)

⇒ **Same genotype may lead to different phenotypes depending on the system** (despite the same mesoclimate!)

⇒ **Estimating phylloclimate would enable a more robust estimation of the genotype-phenotype relationship**

Why phylloclimate may be important when phenotyping?

Characterizing the environment actually driving the phenotype of an individual

A common solution:

using Controlled Environment (phytotron)

with the hope to « fix » the plant environment,
and so to set up reproductible phenotyping experiments

=> but is light so really "fixed" in growth chambers?
between chambers and within a given chamber? At which scale?

A focus on the case of the light environment

Why phylloclimate may be important when phenotyping?

Diversity!

- Chamber types



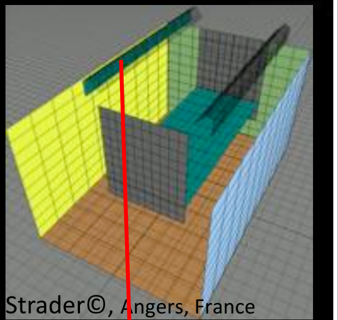
- Lighting systems: simple *vs.* complex, isotropic *vs.* directional

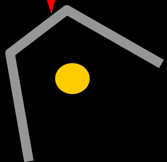



- Given plant: isolated *vs.* population, rosette *vs.* tall plant

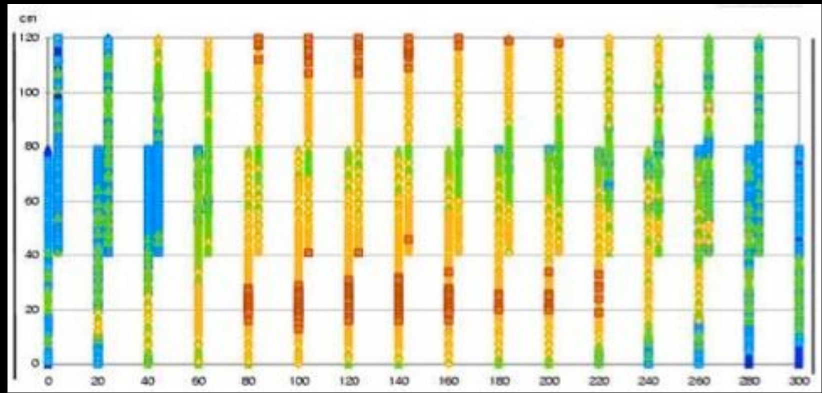


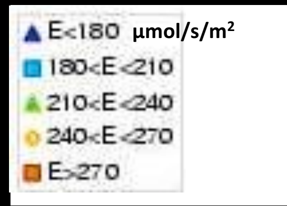

Light heterogeneity



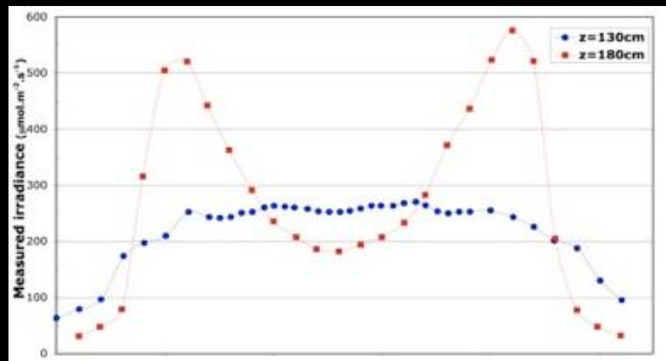


- Spatially (on a horizontal plane)





- Spatially (in 3D)



=> What is the irradiance of individual plant (organ)?

Light phylloclimate in phytotrons

Estimating plant (organ) irradiance

- **by measurement**

  => difficult at the organ scale
  => Commonly approximated by **taking pictures from zenith**

- **by coupling measurement and simulation**

  e.g., "Projecting incident radiation on 3D plant" (Chenu et al, 2005)

1. Measuring the "incident" radiation above the given plants using the "6-face Turtle" PAR sensor
2. Generating the 3D architecture of plants using AMAP software
3. Calculating the irradiance of the 3D mock-up lit by 6 virtual "equivalent" sources using Archimed software (Dauzat, FSPM' 04)

⇒ Limitations may exist: difficulty of accurately sampling the "incident" radiation both spatially and directionally:
- directional lighting systems
- tall plants

- **by modeling**

  3D light transfer e.g. using Monte Carlo ray tracing ***--> the sec2 model*** (Chelle et al., 2007)

Light phylloclimate in phytotrons

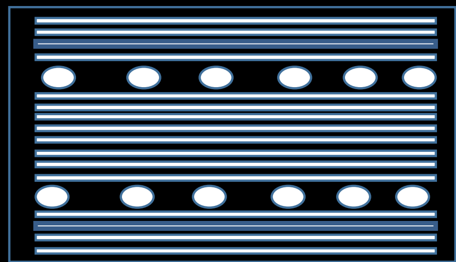
Simulation with the sec2 model

- The given growth chambers

Strader walk-in chamber

- 2 // ramps with 18 Philips HPIT 400W lamps each and a focusing system (3 mirrors)
- glossy and grey walls

Conviron PGR15 reach-in chamber



grey walls

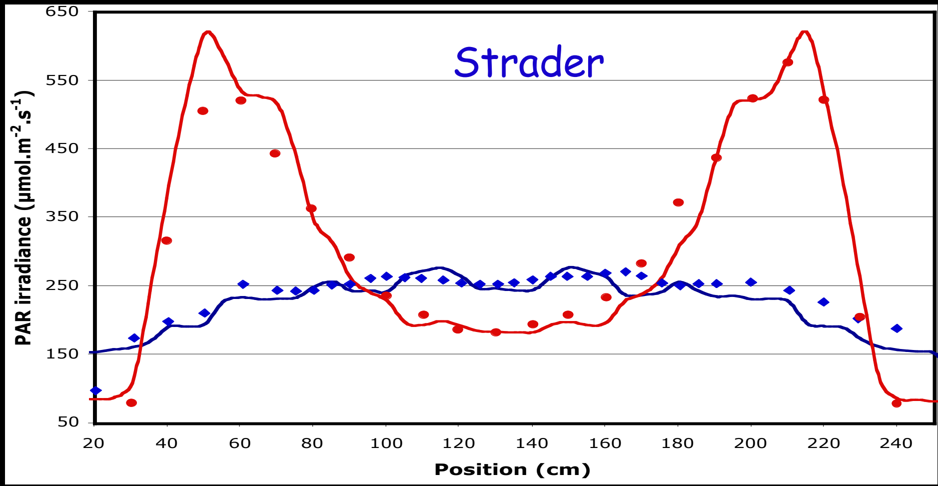
- 2 x 6 OSRAM Sylvania 100W Lamp
- 4x 4 Sylvania GTE Cool White 160W Neon

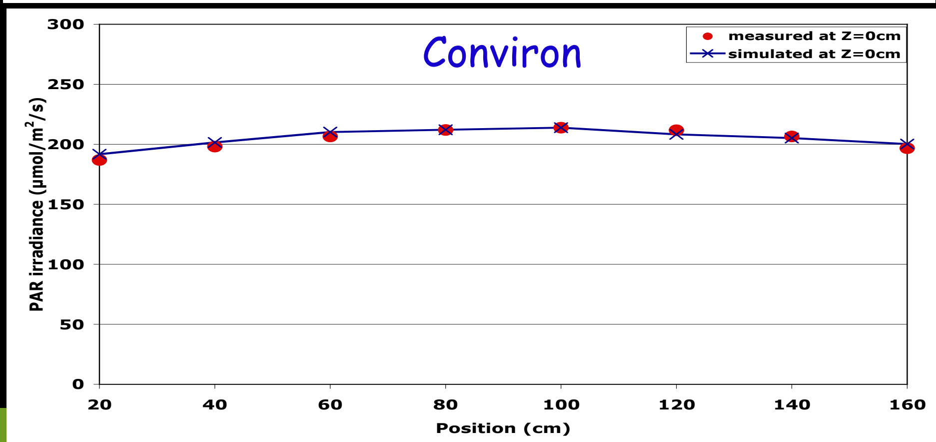
Light phylloclimate in phytotrons

Simulation with the sec2 model

Evaluation

In an empty chamber

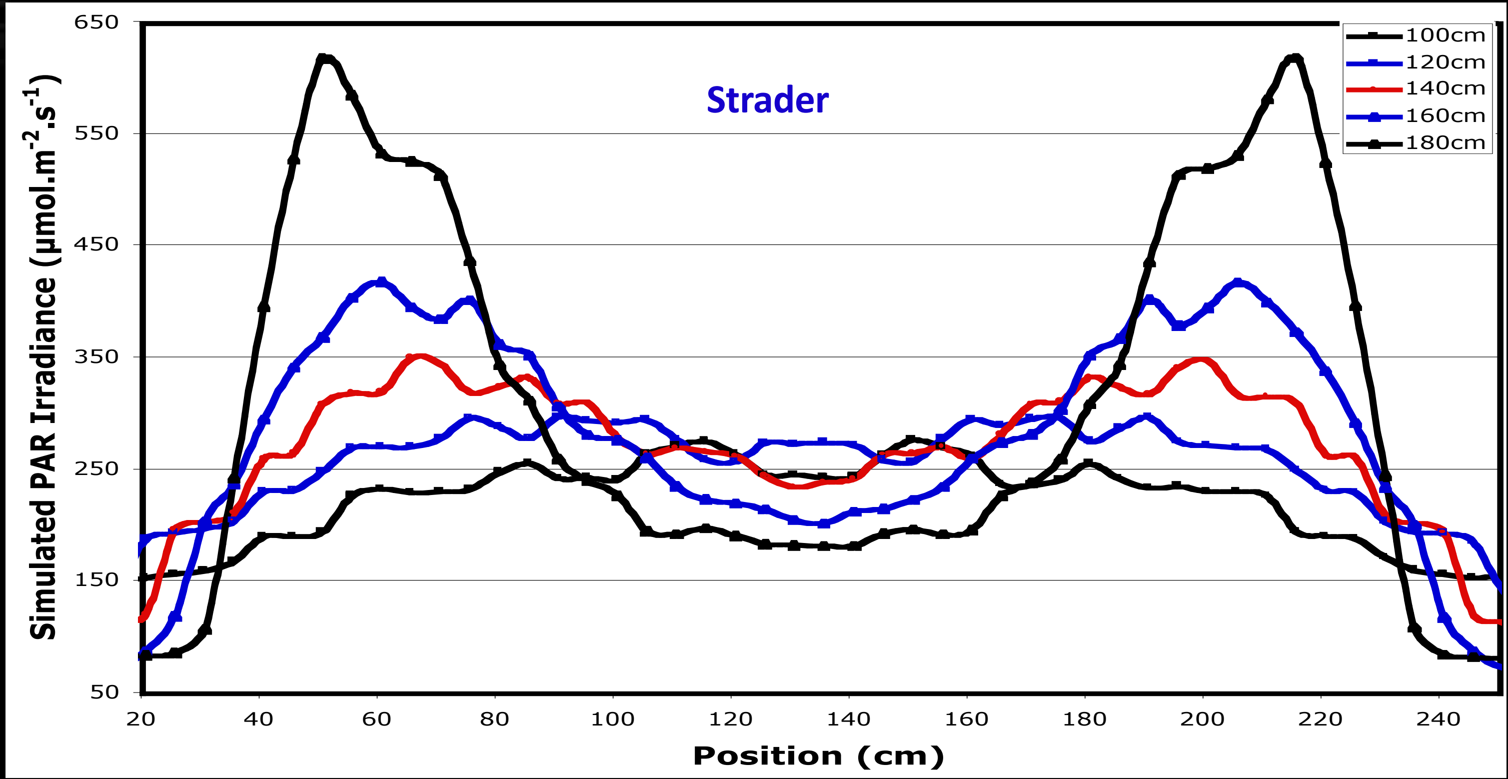




Light phylloclimate in phytotrons

Spatial variability simulation

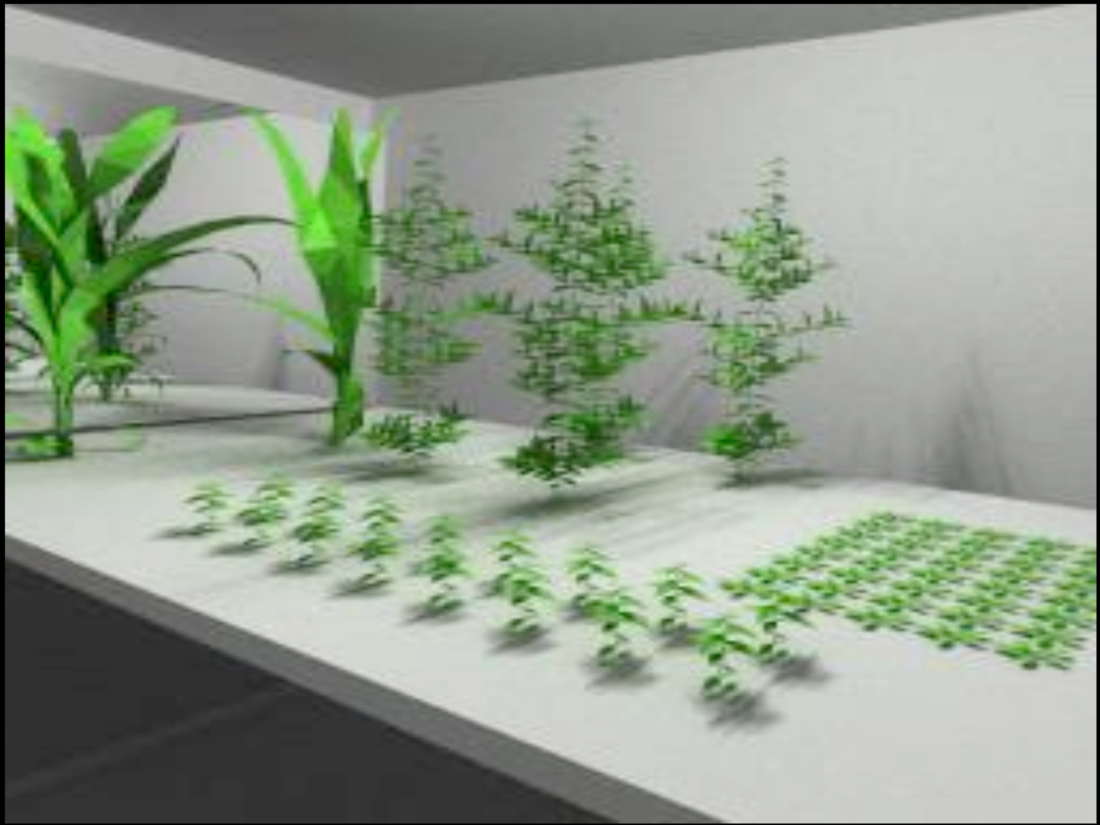
In an empty chamber



Light phylloclimate in phytotrons

Light phylloclimate simulation

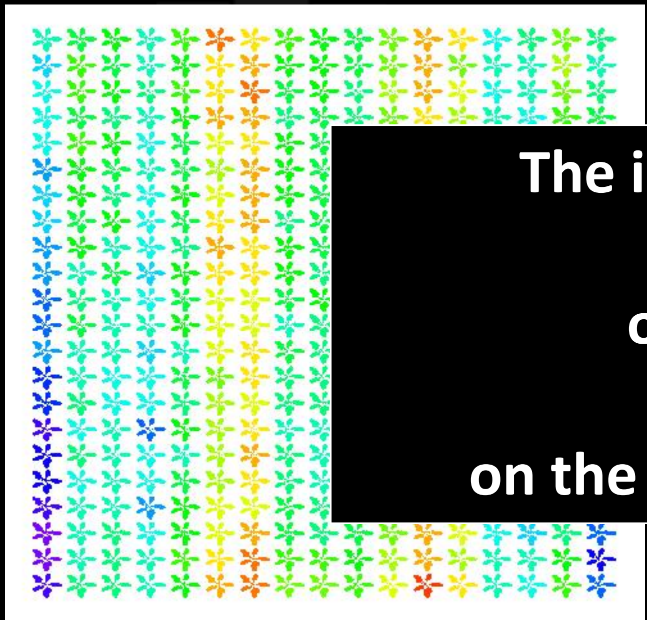
**Sec2 enables
the simulation of
heterogeneous canopies
e.g. contrasted morphological phenotypes**



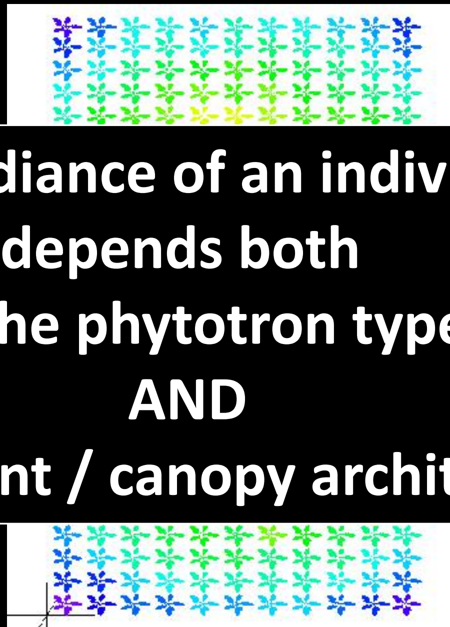
Light phylloclimate in phytotrons

Plant irradiance simulation

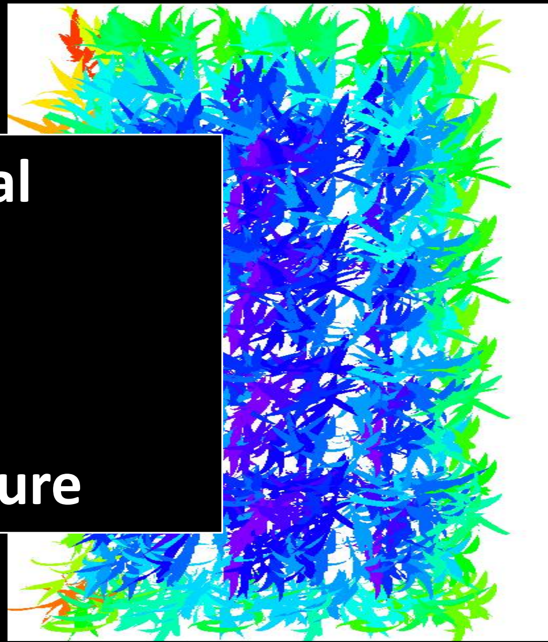
Arabidopsis & Strader



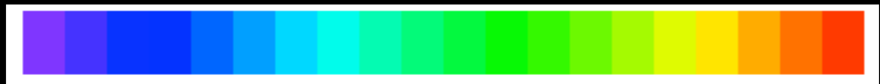
Conviron



Maize & Strader



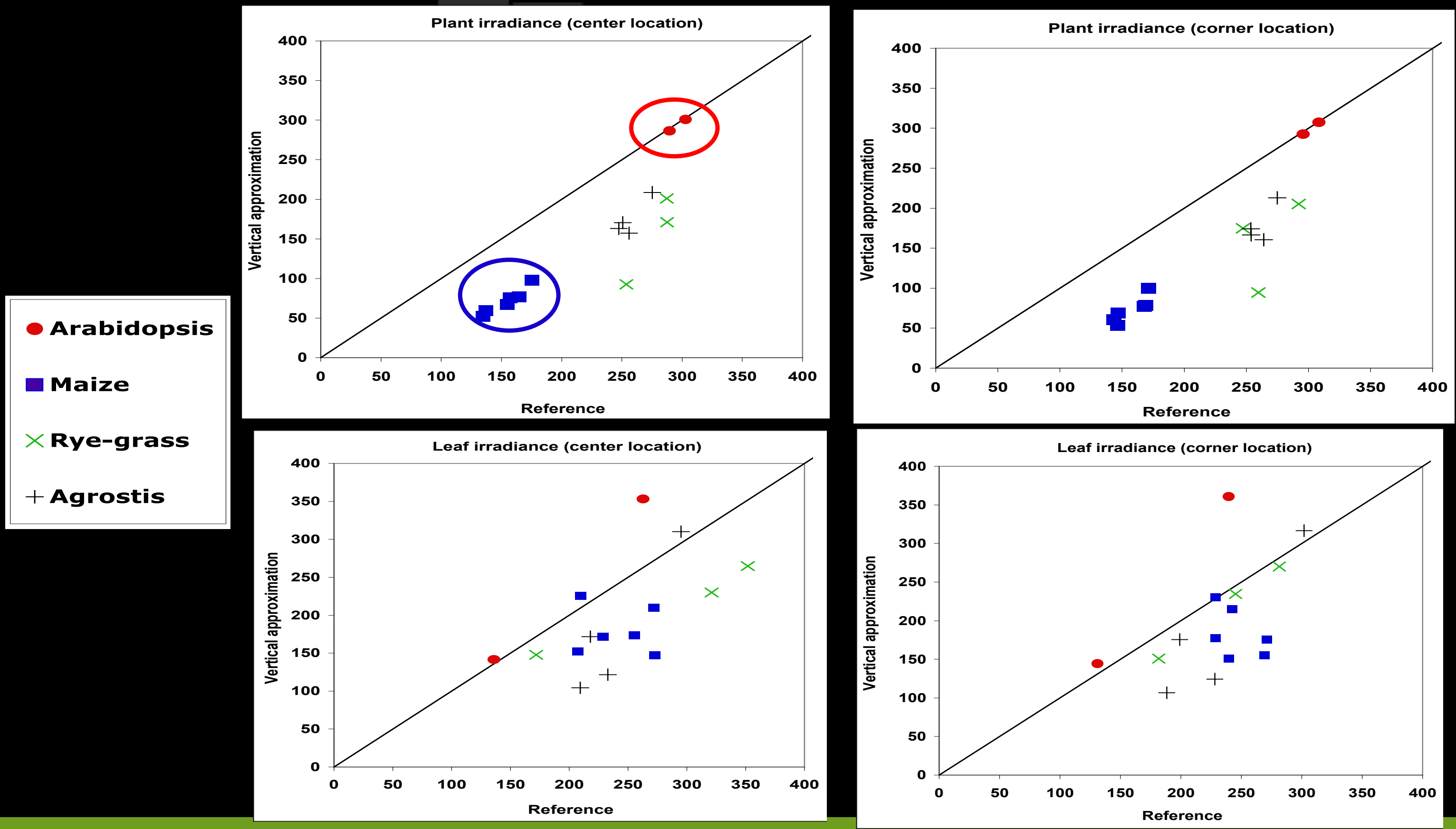
The irradiance of an individual depends both on the phytotron type AND on the plant / canopy architecture

min  max

Plant irradiance

Light phylloclimate in phytotrons

Evaluation of the method based on the projected leaf area

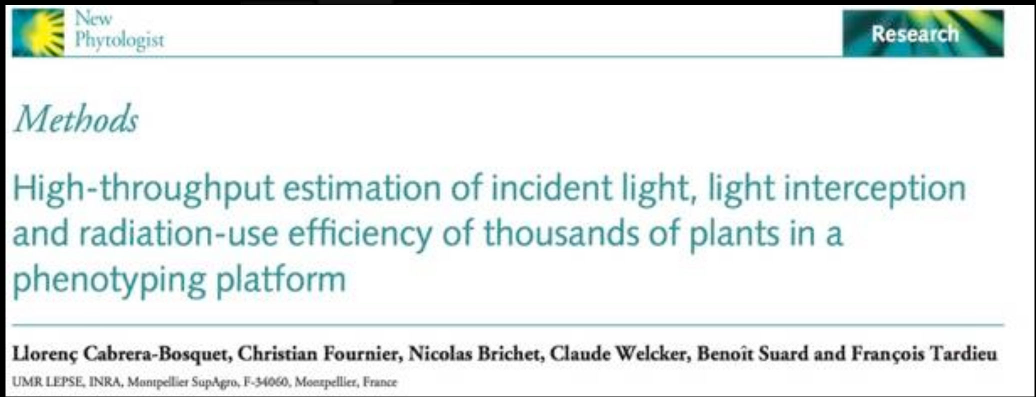


At the plant scale,
importance of the
plant architecture
eg rosette vs tall plant

At the leaf scale,
importance of the
specific
leaf orientation
and position (shading)

Why phylloclimate may be important when phenotyping?

Do not forget greenhouses !


New Phytologist

Research

Methods

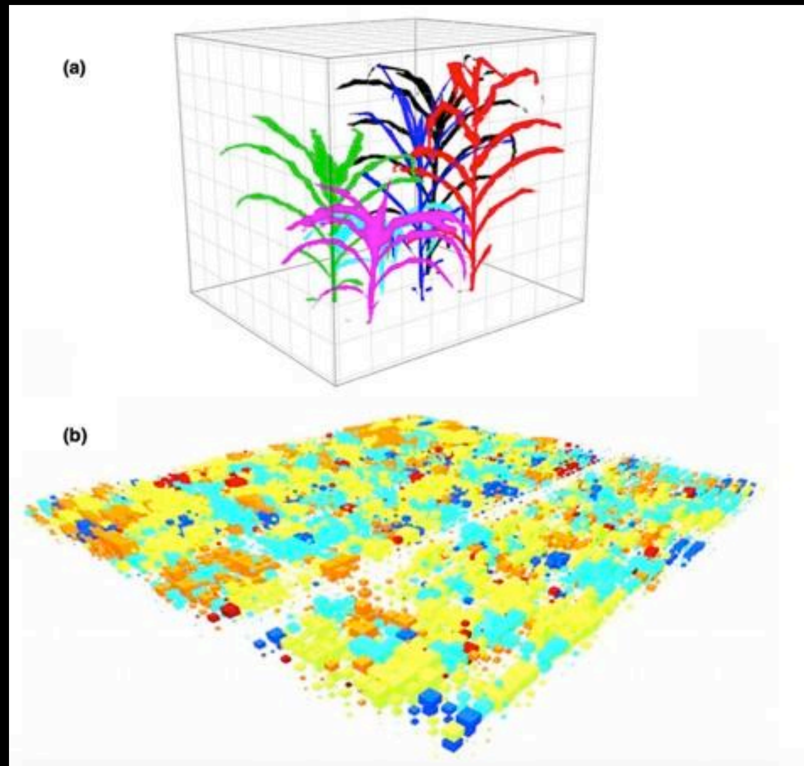
High-throughput estimation of incident light, light interception and radiation-use efficiency of thousands of plants in a phenotyping platform

Llorenç Cabrera-Bosquet, Christian Fournier, Nicolas Brichet, Claude Welcker, Benoît Suard and François Tardieu

UMR LEPSE, INRA, Montpellier SupAgro, F-34060, Montpellier, France

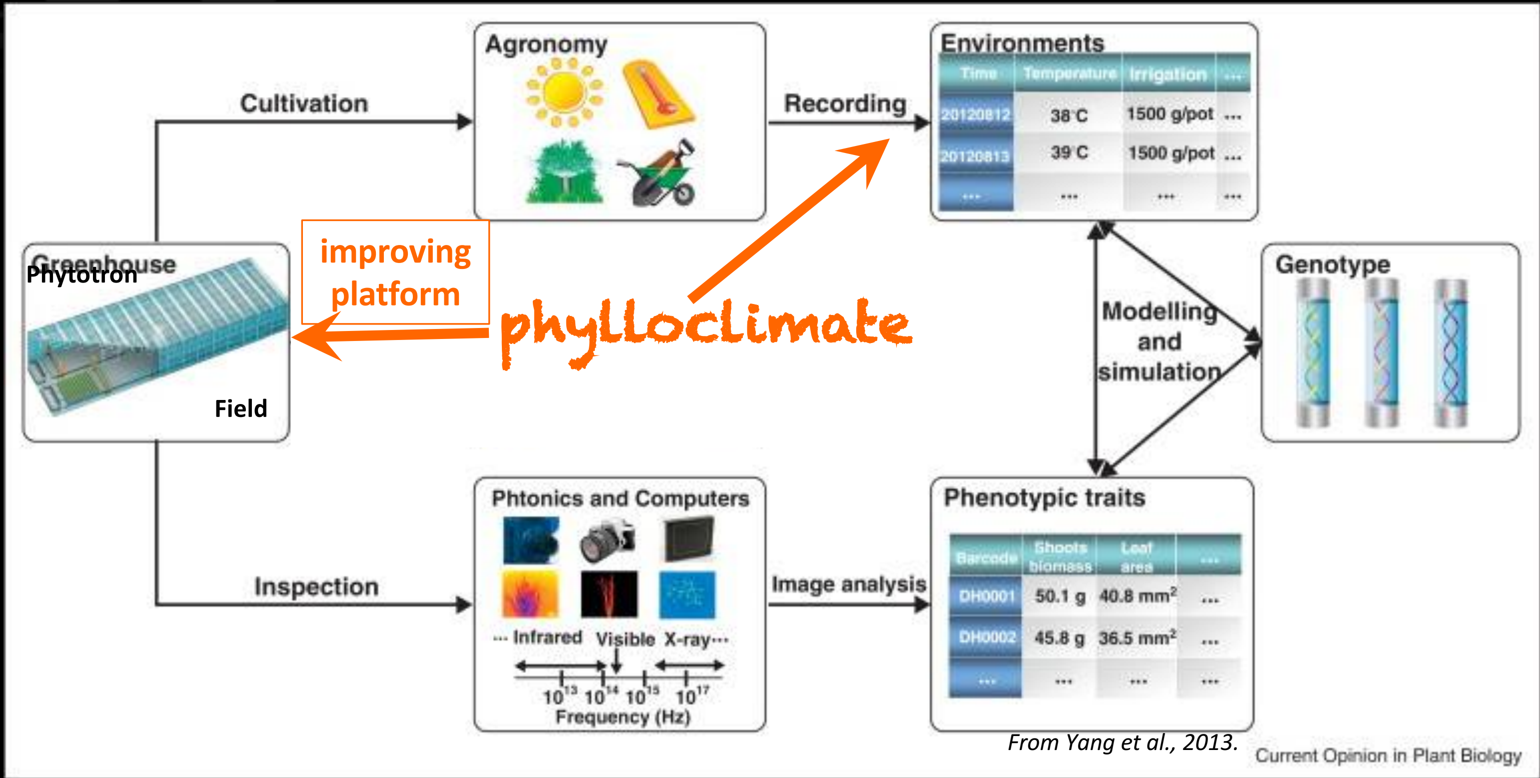
- Dedicated to greenhouse with a lot of individuals
- Combine measurements and use of a turbid-medium model (RATP, Sinoquet) to predict plant irradiance

- *Limit of the voxel size ~hypothesis of the turbid medium*



Phenotyping & phylloclimate

Why phylloclimate may be important when phenotyping?



From Yang et al., 2013. Current Opinion in Plant Biology

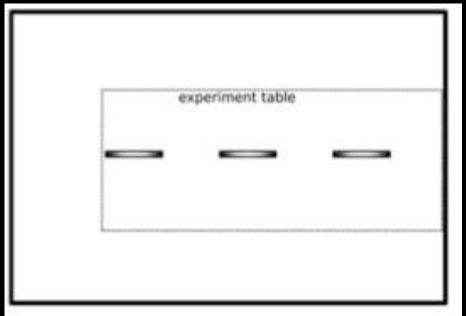
Why phylloclimate may be important when phenotyping?

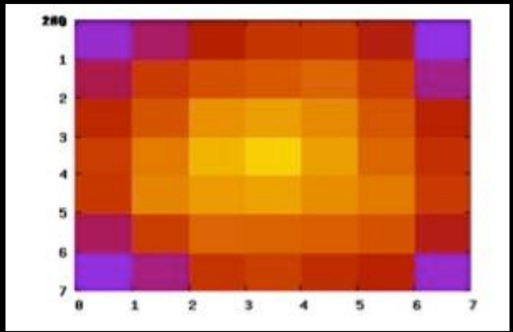
Phylloclimate models may help to design phenotyping system

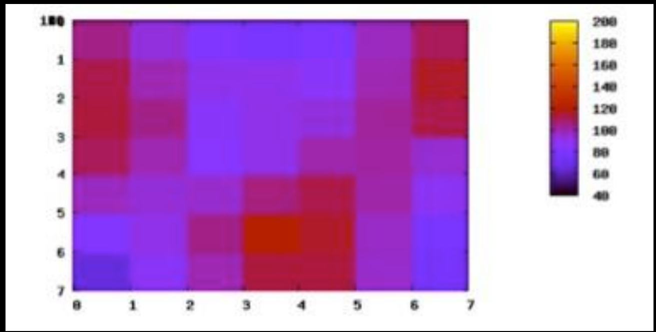
Designing phenotyping systems that limit the environment artifacts

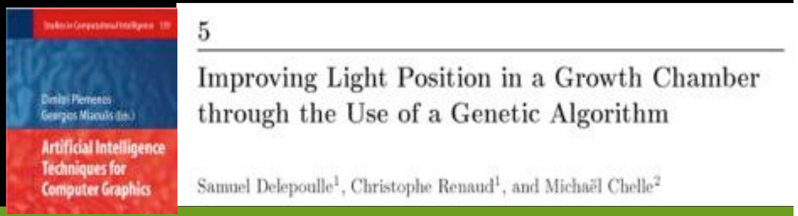
Reverse lighting problem: using a 3D model and Genetic algorithm to optimize the lighting system / homogeneity

Simple case







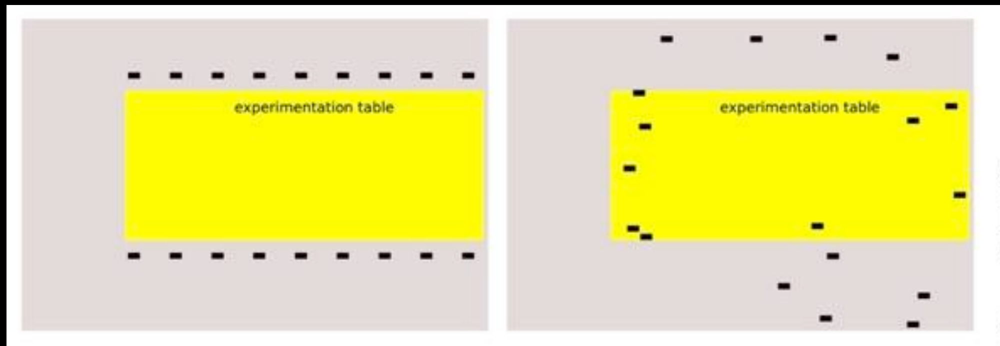


Why phylloclimate may be important when phenotyping?

Phylloclimate models may help to design phenotyping system

Designing phenotyping systems that limit the environment variations

Reverse lighting problem: using a 3D model and Genetic algorithm to optimize the lighting system / homogeneity



5

Improving Light Position in a Growth Chamber through the Use of a Genetic Algorithm

Samuel Delepoulle[1], Christophe Renaud[1], and Michaël Chelle[2]

Satisfying but uncommon results

Future: Optimize the light system / plant irradiance homogeneity?
Develop “agile” phenotyping systems ?

Why phylloclimate may be important when phenotyping?

Do not forget greenhouses !

frontiers in PLANT SCIENCE

ORIGINAL RESEARCH ARTICLE
published: 18 February 2014
doi: 10.3389/fpls.2014.00048

Optimizing illumination in the greenhouse using a 3D model of tomato and a ray tracer

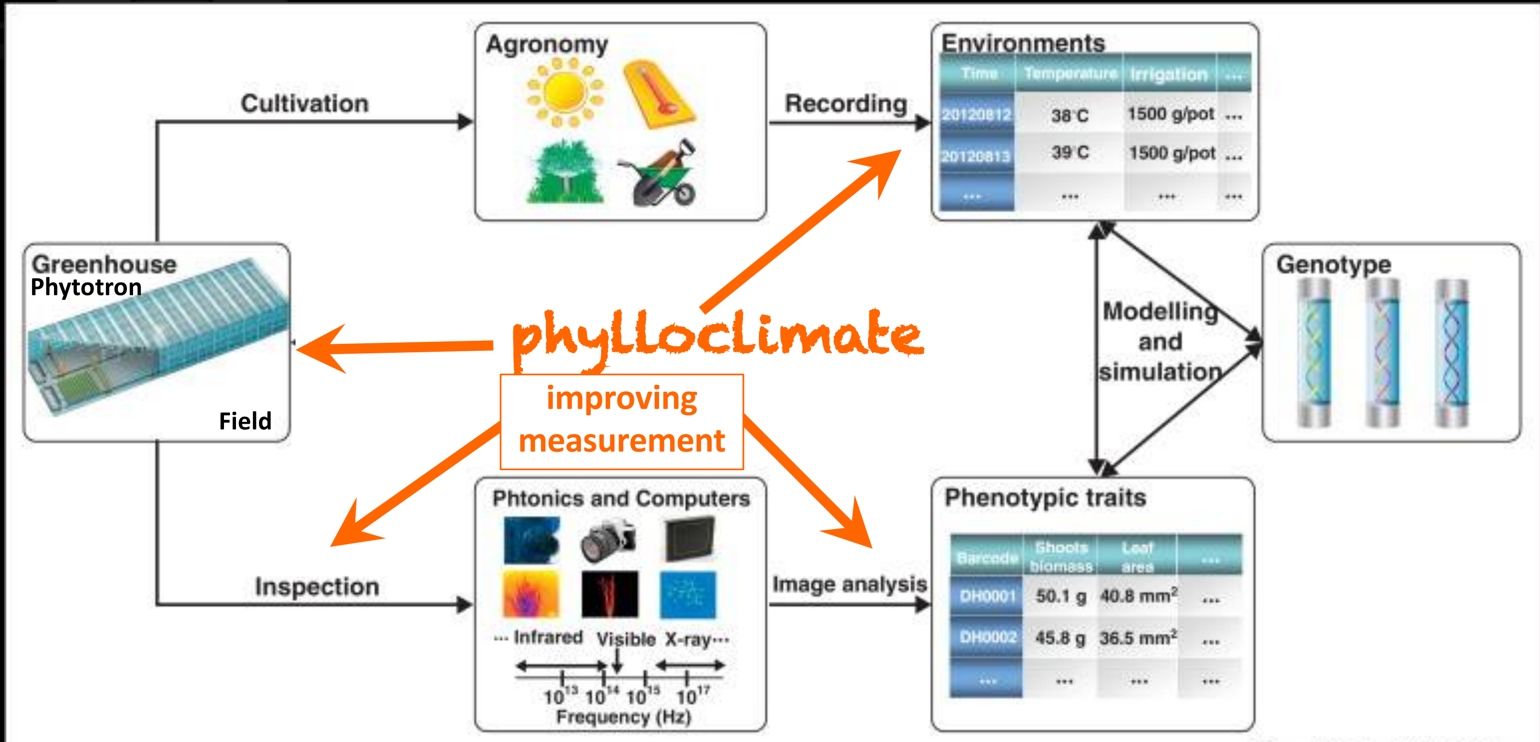
Pieter H. B. de Visser[1], Gerhard H. Buck-Sorlin[2] and Gerie W. A. M. van der Heijd*

[1] *Department of Greenhouse Horticulture, Wageningen University and Research Centre, Wageningen, Netherlands*

New lighting systems
eg LED, hybrid, 3D,
may offer more degrees of freedom
to design more efficient systems

Phenotyping & phylloclimate

Why phylloclimate may be important when phenotyping?



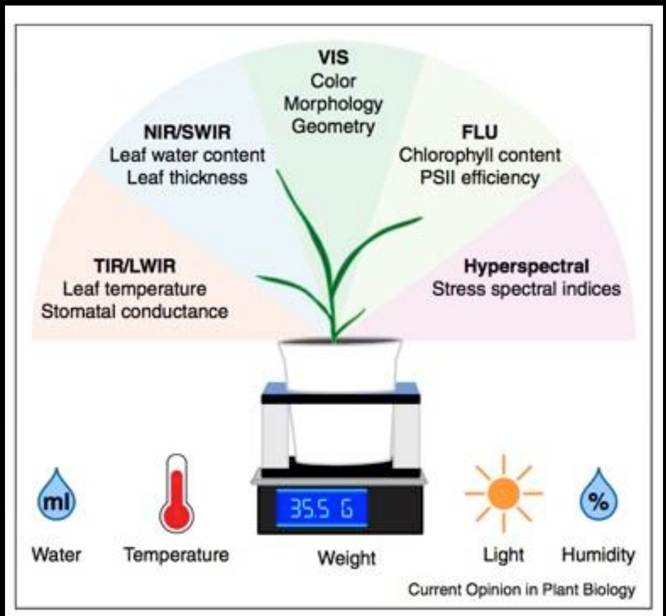
From Yang et al., 2013. Current Opinion in Plant Biology

Phenotyping & phylloclimate

Why phylloclimate may be important when phenotyping?

Help to interpret (design) indirect measurement

Phylloclimate models, based on **3D transfer equation**, can simulate indirect measurements.



MODELING EFFECTS OF ILLUMINATION AND PLANT GEOMETRY ON LEAF REFLECTANCE SPECTRA IN CLOSE-RANGE HYPERSPECTRAL IMAGING

Mohd Shahrimie M.A[1], Puneet Mishra[1], Stien Mertens[2,3], Stijn Dhondt[2,3], Nathalie Wuyts[2,3], Paul Scheunders[1]*

[1]iMinds - Vision Lab - University of Antwerp, Belgium

Improving Sheet-of-Light Based Plant Phenotyping with Advanced 3-D Simulation

Franz Uhrmann, Lars Seifert, Oliver Scholz, Peter Schmitt, and Günther Greiner

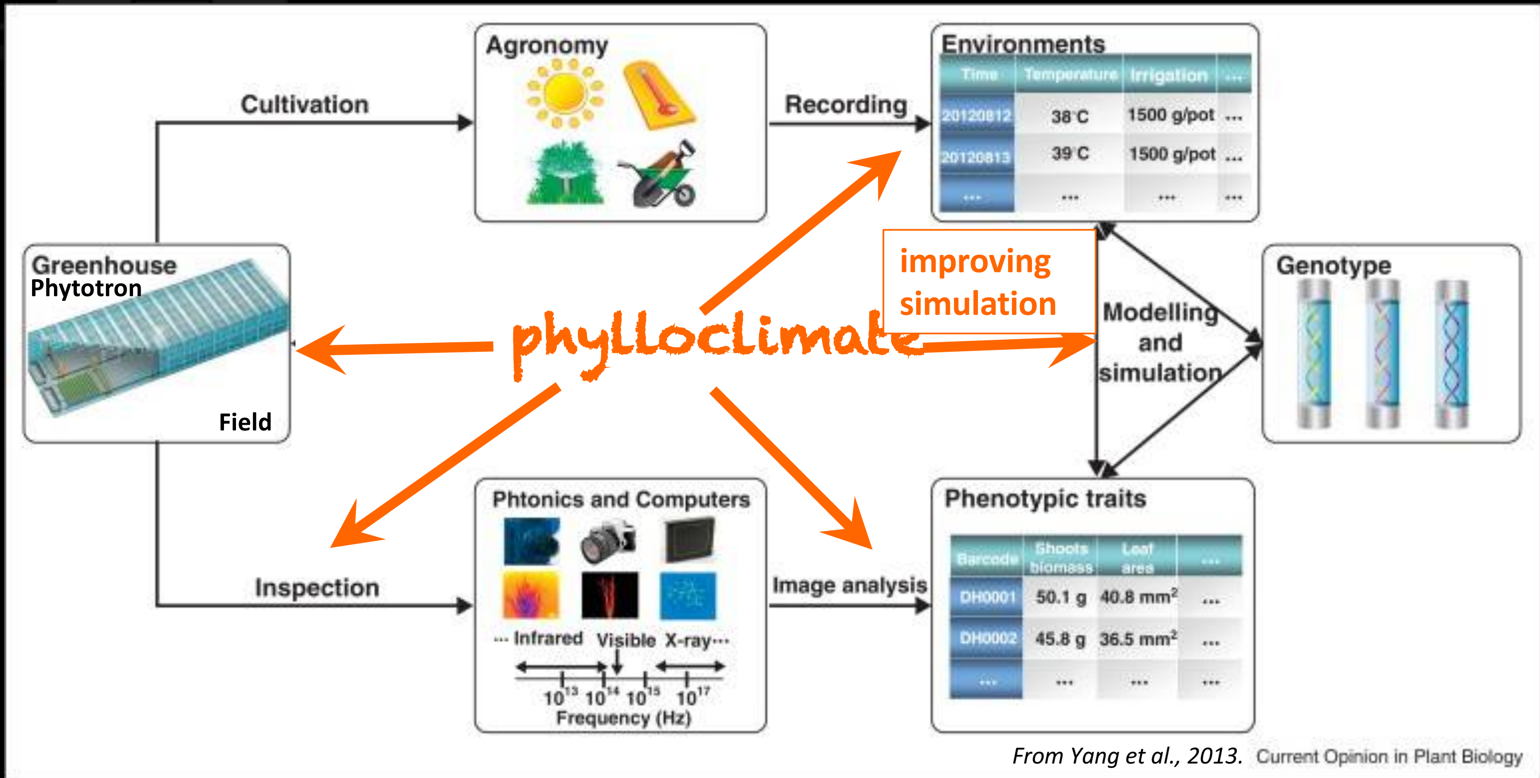
Abbildung 1: Pflanzenmodell (links). Simulationsergebnis mit einer (Mitte) und drei (rechts) Laser-Kamera-Paaren: Dargestellt sind die erfassten Bereiche der Pflanze.

The CALSIF project aiming at developping new field fluorescence sensor

Y Goulas, M. Chelle, F. Baret, I Moya, F Daumard

Phenotyping & phylloclimate

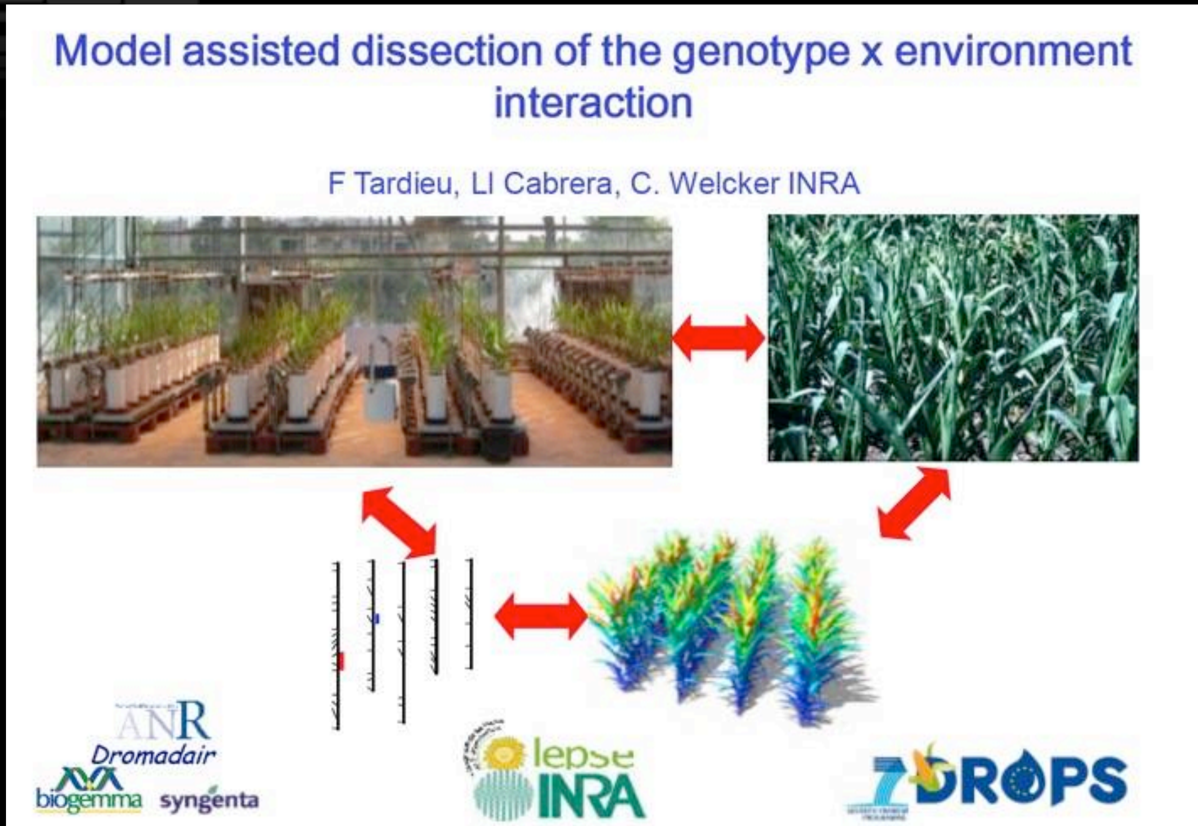
Why phylloclimate may be important when phenotyping?



From Yang et al., 2013. Current Opinion in Plant Biology

Phenotyping & phylloclimate

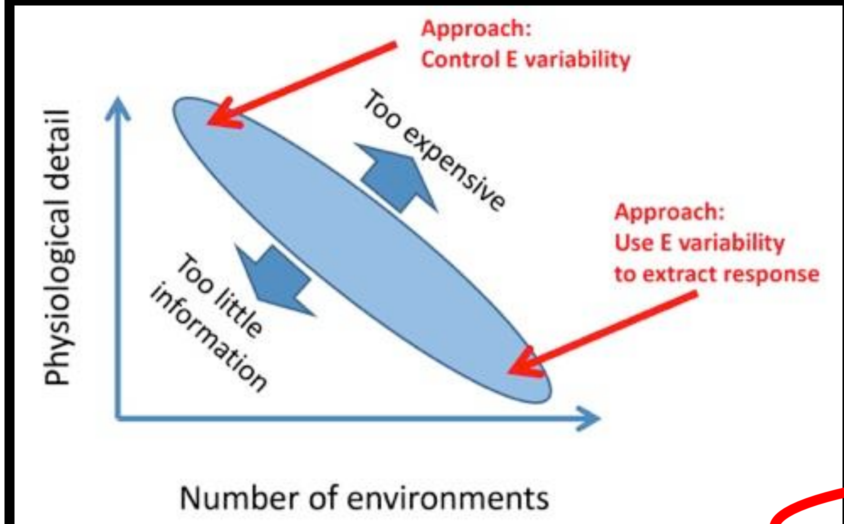
Towards model-assisted phenotyping

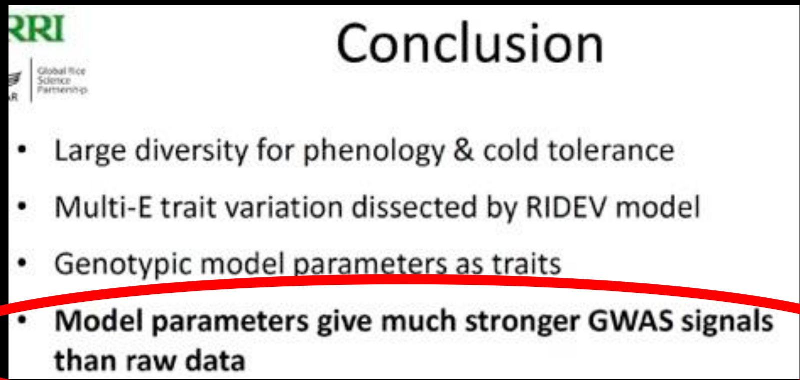


Plant model parameters used as phenotyped traits
+
Individual plants

Phenotyping & phylloclimate

Towards model-assisted phenotyping





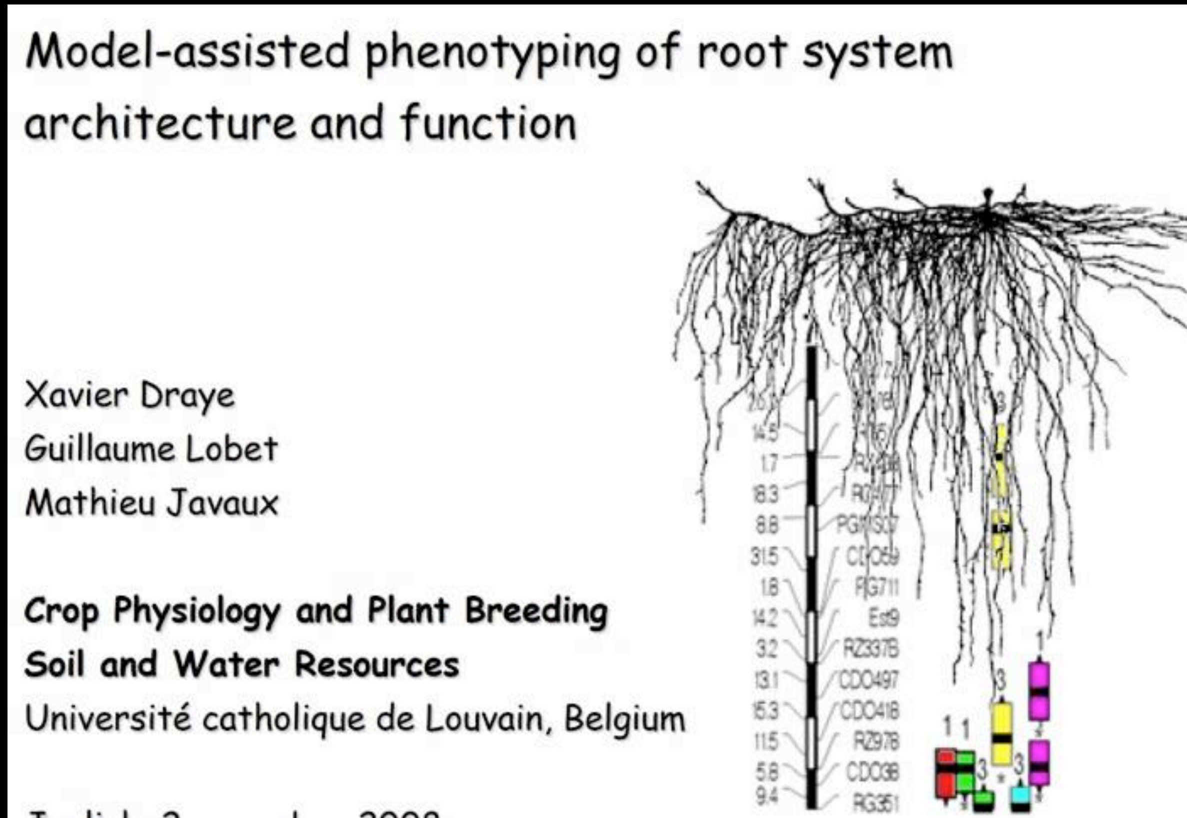
Plant model parameters used as phenotyped traits
+
Multi-environment

Phenotyping & phylloclimate

Towards model-assisted phenotyping

Also useful to phenotype root-soil interactions

It exists ~ phylloclimate models for soils



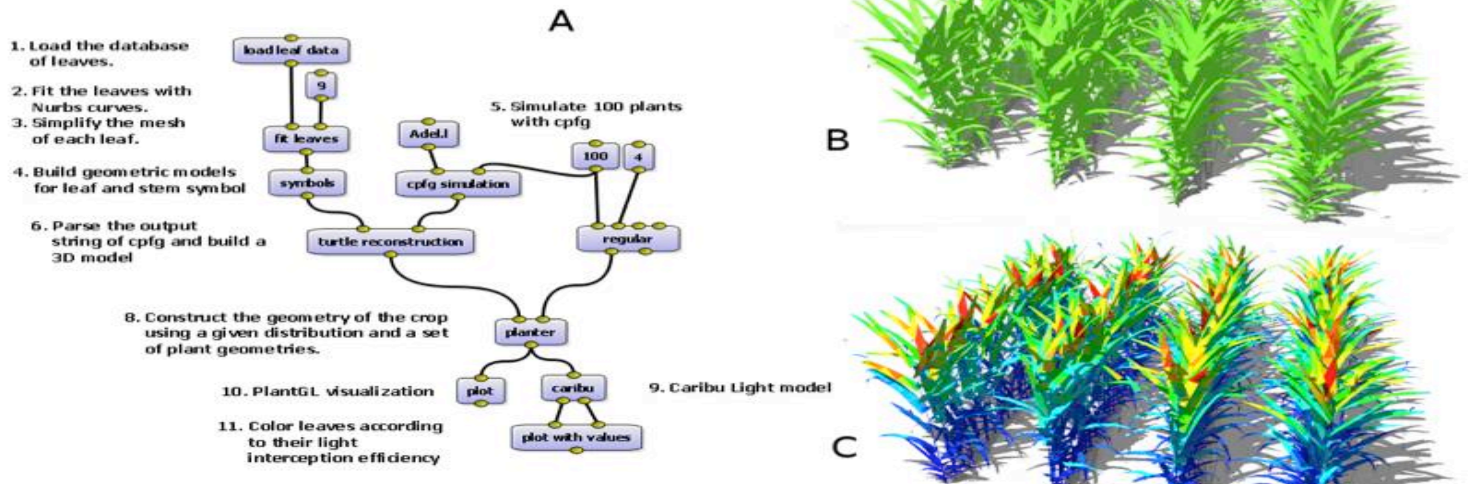
Phenotyping & phylloclimate

Towards collaborative plant modeling…

interdisciplinarity, sharing, factorizing, etc

Emergence of plant modeling platforms

e.g. **OpenAlea plateform** INRIA-INRA-CIRAD

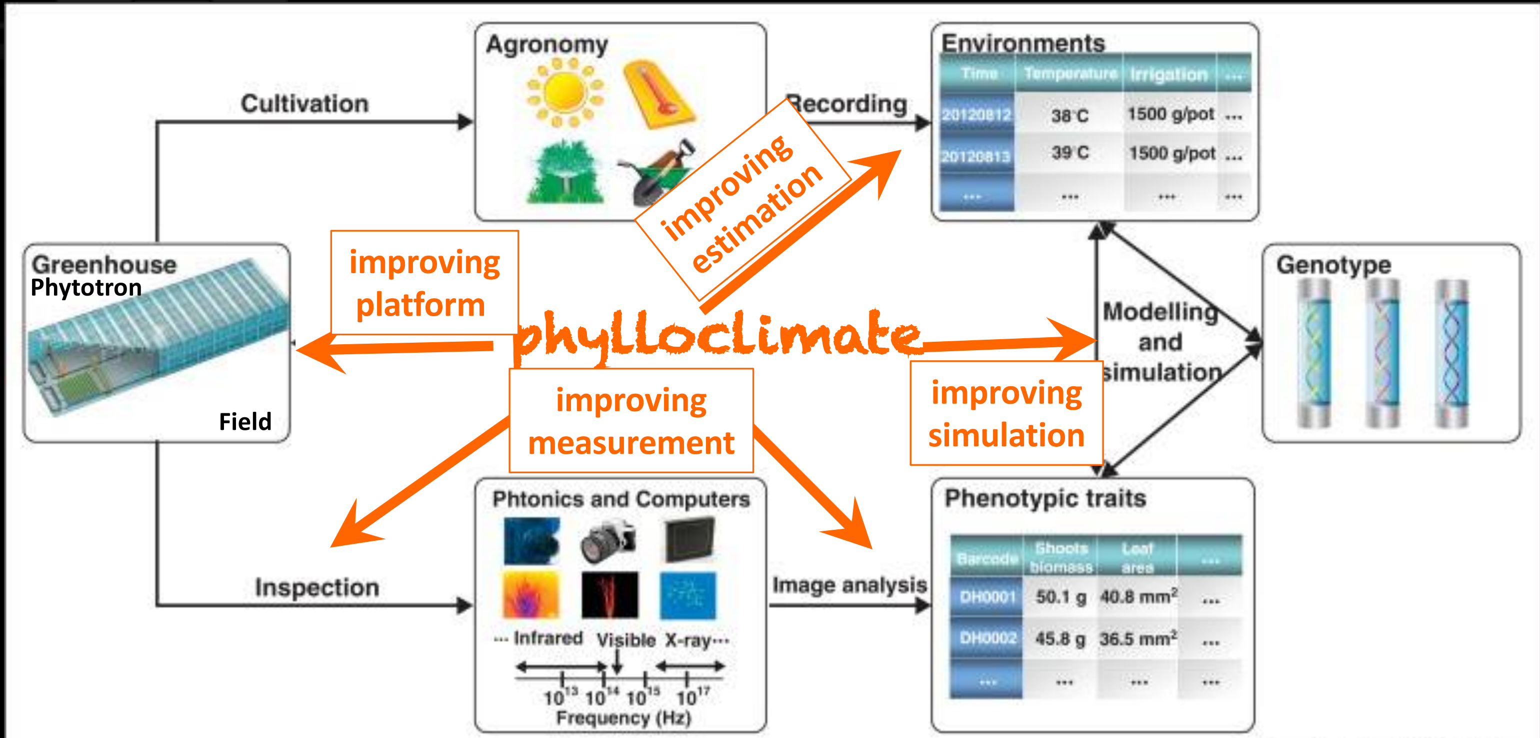


(Pradal et al, 2008, FPB)

=> Communities are ready !

Phenotyping & phylloclimate

Why phylloclimate may be important when phenotyping?



From Yang et al., 2013. Current Opinion in Plant Biology

Why phylloclimate may be important when phenotyping?

Take-home messages

- ❑ **Characterize the environment at the right spatio-temporal scales** (Think to phylloclimate 😃)
  - to avoid misunderstanging of the G X Ê
  - Distribution (variance) >> average (fluctuation)
  - to easy the integration of data coming from various phenotyping systems
- ❑ **Phylloclimate models may be useful in improving the chain of phenotyping**
- ❑ **Model-assisted phenotyping may take benefits from phylloclimate** (e.g. FSPM, assimilation)
- ❑ **The emergence of big data approach in phenotyping would simplify the down-scaling**

INRA
SCIENCE & IMPACT

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